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# Regionalized Equations for Bankfull-Discharge and Channel Characteristics of Streams in New York State: Hydrologic Region 7 in Western New York

## Scientific Investigations Report 2006–5075

U.S. Department of the Interior
U.S. Geological Survey

Cover photo by Barry Baldigo of the Butternut Creek near Jamesville, New York; inserts are of the Tributary to Second Creek at Alton, New York

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# CONVERSION FACTORS AND DATUM

| Multiply | By | To obtain |
|---|---|---|
| inch (in) | 25.4 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second ($m^3/s$) |

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

# Regionalized Equations for Bankfull-Discharge and Channel Characteristics of Streams in New York State: Hydrologic Region 7 in Western New York

By Christiane I. Mulvihill, Anne G. Ernst, and Barry P. Baldigo

## Abstract

Computation of bankfull discharge and channel dimensions (width, depth, and cross-sectional area) at ungaged sites requires equations that relate bankfull discharge and channel dimensions to drainage-area at gaged sites. Bankfull-channel information commonly is needed for watershed assessments, stream channel classification, and the design of stream-restoration projects. Such equations are most accurate if they are derived on the basis of data from streams within a region of uniform hydrologic, climatic, and physiographic conditions and applied only within that region. New York State contains eight hydrologic regions that were previously delineated on the basis of high-flow (flood) characteristics. This report presents drainage areas and associated bankfull characteristics (discharge and channel dimensions) for surveyed streams in western New York (Region 7).

Stream-survey data and discharge records from seven active and three inactive USGS streamflow-gaging stations were used in regression analyses to relate drainage area to bankfull discharge and to bankfull channel width, depth, and cross-sectional area. The resulting equations are:

bankfull discharge ($ft^3/s$) = 37.1 (drainage area, in $mi^2$)$^{0.765}$
bankfull channel width (ft) = 10.8 (drainage area)$^{0.458}$
bankfull channel depth (ft) = 1.47 (drainage area)$^{0.199}$
bankfull channel cross-sectional area ($ft^2$) = 15.9 (drainage area)$^{0.656}$

The coefficients of determination ($R^2$) for these four equations were 0.94, 0.89, 0.52, and 0.96, respectively. The high coefficients of determination for three of these equations (discharge, width, and cross-sectional area) indicate that much of the range in the variables was explained by the drainage area. The low coefficient of determination for the equation relating bankfull depth to drainage area, however, suggests that other factors also affected water depth. Recurrence intervals for the estimated bankfull discharge of each stream ranged from 1.05 to 3.60 years; the mean recurrence interval was 2.13 years. The 10 surveyed streams were classified by Rosgen stream type; most were C- and E-type, with occasional B- and F-type cross sections. The equation (curve) for bankfull discharge for Region 7 was compared with those previously developed for four other hydrologic regions in New York State. The differences confirm that the hydraulic geometry of streams is affected by local climatic and physiographic conditions.

## Introduction

Streambank erosion and the resulting sedimentation of streams can affect the water quality of reservoirs, endanger aquatic life, and jeopardize private and public lands and associated infrastructure. Streams throughout New York State that have abnormally high rates of erosion and sedimentation are undergoing restoration efforts to improve bank and bed stability. Stream restoration procedures have traditionally consisted of straightening, widening, and deepening the channel, hardening the banks, and imposing static stream geometry—all of which can cause permanent ecological disruption. Recent stream-restoration projects, in contrast, have begun to use an approach that strives toward replication of stable-reach characteristics, such as the relation between drainage-area and channel cross-section dimensions, and the relations among channel dimensions, flow patterns, and water-surface profiles. Bankfull discharge and bankfull channel dimensions of streams that are not gaged can be derived by using equations (curves) that have been developed on the basis of data from stable reaches on nearby gaged streams. Channel geometry data from these nearby reference reaches provides the foundations for Natural-Channel-Design (NCD) restoration techniques to recreate geomorphically stable stream reaches. The stream geometry obtained through NCD techniques structurally resembles that of natural streams and, thus, can slow erosion and sedimentation and allow regeneration of aquatic ecosystems that are more diverse and functionally complete than those that typically result from the hardening of streambeds and banks.

Bankfull discharge is the most useful stream feature for determining the relation between drainage-area and stream-channel dimensions. Bankfull discharge is the flow that reaches the transition between the channel and its flood-plain and is thus a morphologically significant streamflow (Leopold and others, 1964). It may be functionally defined and identified as the stage or flow at which the stream is about to overtop its banks (Leopold and others, 1964; Leopold, 1994), and is reported to occur every one to two years, or 1.5 years on average (Rosgen, 1994). Bankfull discharge is the flow that moves the most sediment over time, due to the combination of its force and frequency (Wolman and Miller, 1960; Leopold, 1994). Bankfull discharge influences the relations between drainage area and stream-channel dimensions in two ways. First, it commonly occurs at a relatively discrete and identifiable stage, and so a system for classifying streams has been developed on the basis of channel dimensions at bankfull stage (Rosgen, 1996). Second, relations between drainage area and discharge, and between drainage area and channel dimensions, are relatively constant at bankfull stage in stable streams of a given class within a given hydrologic region (Leopold and others, 1964; Rosgen, 1996).

Predicting stable-channel characteristics of an unstable, ungaged stream requires equations that are based on data from stable streams that are close to the ungaged stream, are subject to similar precipitation rates and climatic conditions, and whose drainage basins have similar soils, recharge patterns, flow patterns, and physiographic characteristics. Deriving channel-geometry equations on the basis of data from stable streams within the same hydrologic region can minimize variance in each variable and increase the accuracy of the equations. The New York State Hydrologic and Habitat Modification (HHM) subcommittee of the New York State Nonpoint-Source Coordinating Committee (NSCC) is overseeing a statewide cooperative effort to develop such equations through a system created by the New York City Department of Environmental Protection Stream Management Program (NYCDEP-SMP; Miller and Davis, 2003; Powell and others, 2004). Similar efforts are being conducted in other parts of North America; three examples include those in Vermont (Jaquith and Kline, 2001), southern Ontario (Annable, 1996), and the Pennsylvania-Maryland Piedmont area (White, 2001). The resulting equations, which reflect local precipitation rates, hydrologic conditions, physiographic characteristics, and soil properties, are expected to provide more reliable results than the currently available channel-geometry equations that represent widespread and disparate geographic regions, such as the eastern United States (Dunne and Leopold, 1978).

## Approach

In 2001, the U.S. Geological Survey (USGS), in cooperation with the New York State Department of Environmental Conservation (NYSDEC), the New York State Department of Transportation (NYSDOT), and the New York City Department of Environmental Protection (NYCDEP), began a six-year study to define the relations between drainage area and channel characteristics for the eight hydrologic regions of New York State (excluding Long Island) that were previously established to predict flood flows of unregulated streams (Lumia, 1991). The New York State Department of State (NYSDOS) joined in 2005. Boundaries of the hydrologic regions (fig. 1) were used as preliminary hydrologic-region boundaries to group streams with similar characteristics. Equations have been developed for Regions 4 and 4a in the Catskill Mountains, New York (Miller and Davis, 2003), Region 5 in central New York (Westergard and others, 2005), and Region 6 in the southern tier of New York (Mulvihill and others, 2005). Objectives of the ongoing study are to (1) complete bankfull surveys on selected streams in all eight regions to verify and (or) redefine these boundaries; (2) assess all streams for key features of the Rosgen (1996) stream classification system; namely, channel-entrenchment ratio (ratio of flood-plain width to bankfull-channel width), channel width-to-depth ratio, water-surface slope, channel materials, and channel sinuosity (ratio of stream length to valley length); and (3) assess the accuracy of statewide bankfull equations by grouping channel-geometry relations across the eight regions by stream type in accordance with the Rosgen stream-classification system (Miller and Davis, 2003).

Rosgen's (1996) stream-classification system was created to provide reliable stream descriptions for use in evaluations of channel stability and in the design and simulation of stable conditions in ungaged stream reaches. The geomorphologic characteristics defined by Rosgen (1996) that correspond to bankfull stage were chosen for their consistency among streams with similar physiographic conditions for a given drainage-basin size, and among streams subject to similar climatic conditions (Rosgen, 1994, 1996).

Hydrologic Region 7 (fig. 1) is the fifth of the eight hydrologic regions studied as part of this project. Region 7 encompasses an area bounded by Lake Ontario to the north, the Oswego River and the southern part of the Oneida Creek basin to the east, and the Tonawanda Creek basin to the west. It includes the northern half of the Genesee River basin, and most of its southern boundary is defined by the southern ends of the Finger Lakes (Lumia, 1991). This region does not contain many actively gaged streams that are unregulated and have at least 10 years of peak flow record; therefore, data from three discontinued streamflow-gaging stations was included in the development of the equations.

The hydrologic regions defined by Lumia (1991) were based on multiple linear regression analyses that related the 50-year peak-discharge recurrence interval to basin characteristics such as drainage area, main-channel slope, basin storage, mean annual precipitation, percentage of basin covered by forest area, mean main-channel elevation, and a basin-shape index (ratio of basin length to basin width). These boundaries will later be compared with those developed from bankfull survey data collected during this and other studies, and adjusted if needed.

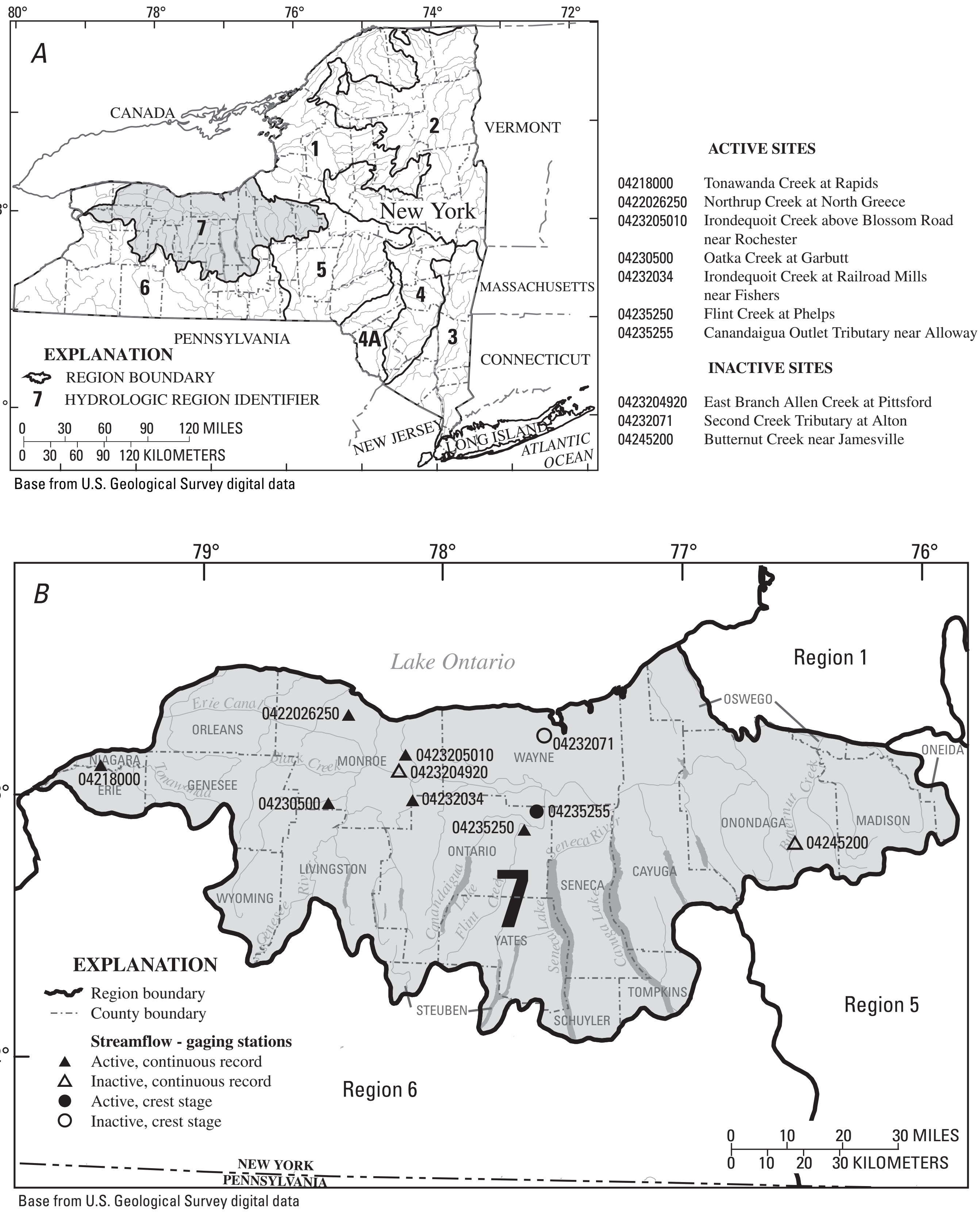



**Figure 1.** Hydrologic regions of New York: *A*. Hydrologic-region boundaries as defined by Lumia (1991). *B*. Locations of the seven active and three inactive streamflow-gaging stations used in 2003-04 stream survey in Region 7.

## Purpose and Scope

This report (1) describes the methods of site selection and data collection and analysis; (2) presents the relations between drainage area and bankfull width, depth, cross-section area, and discharge; and (3) compares bankfull-discharge equations developed for Region 7 with previously developed equations for Regions 4, 4a, 5 and 6.

# Methods

Ten streams were surveyed during the 2003-04 field season. The methods used to collect and analyze the data in this report are described in detail in Powell and others (2004).

## Site Selection

The streams were selected to represent a wide range of drainage-area sizes so that the resulting equations would be applicable to a majority of streams within the hydrologic region. Other selection criteria (Miller and Davis, 2003) for study reaches are listed below:

- Must contain a USGS streamflow-gaging station with at least 10 consecutive years of annual peak-discharge data.
- Must be primarily alluvial, unregulated, and consist of a single channel at bankfull stage.
- Must include at least two sequences of a pool and a riffle, or be at least 20 bankfull widths in length.
- Must have readily identifiable bankfull indicators (defined in following section).
- Must meet the minimum requirements for slope-area calculation of discharge (uniform channel geometry; flow confined to a single, trapezoidal channel; and water-surface elevation drop of at least 0.50 ft within the reach (Dalrymple and Benson, 1967), so that surveyed data can be used reliably in hydraulic analysis and calculation of bankfull discharge.
- Should represent a single Rosgen (1996) stream type, if possible. This was not possible at two of the ten reaches, as explained further on.

USGS streamflow-gaging stations are not always located on geomorphically stable stream reaches because land-owner permission, access to the site, and the need for the safe measurement of high flows often dictate where a gage is located. Bridges and other structures may cause local channel instability at stream reaches near streamflow-gaging stations. To assess channel stability at streamflow-gaging stations used in this study, two methods were employed. At active sites (Canandaigua Outlet Tributary near Alloway (USGS station number 04235255), Northrup Creek at North Greece (0422026250), Irondequoit Creek at Railroad Mills near Fishers (04232034), Flint Creek at Phelps (04235250), Irondequoit Creek above Blossom Road near Rochester (0423205010), Oatka Creek at Garbutt (04230500), Tonawanda Creek at Rapids (04218000)) and recently discontinued sites (East Branch Allen Creek at Pittsford (0423204920), Butternut Creek near Jamesville (04245200)) stability was assessed through inspection of the most recent analysis of flow-measurement data for evidence of scour, deposition, and frequent shifting of bed material. At the site that had been discontinued for a long period of time (Second Creek Tributary at Alton (04232071)), three discharge measurements were made during the study period to define the stage-to-discharge relation, which was compared with the last known relation when the site was active. Significant discrepancies between the two relations would have been indicative of channel instability.

The selected sites were referred to as calibration sites because they were used to develop, or calibrate, the channel-geometry equations. Region 7 contained 17 active sites with 10 or more years of peak flow record. The site visits indicated that all of the sites with small drainage areas (<2 mi$^2$) were unsuitable for gage calibration surveys because their flows were artificially regulated. Therefore, one site that had been inactive for 18 years (Second Creek Tributary at Alton (04232071)) and two recently discontinued sites (East Branch Allen Creek at Pittsford (0423204920) and Butternut Creek near Jamesville (04245200)) were included in the study.

## Data Collection

Preliminary reconnaissance of all sites entailed marking bankfull indicators, cross-section locations, and reach boundaries. Bankfull indicators consisted of: (1) a topographic break from vertical bank to flat flood-plain; (2) a topographic break from steep slope to gentle slope; (3) change in vegetation (for example, from treeless to trees); (4) textural change in sediment; (5) a scour break, or elevation below which no fine debris (needles, leaves, cones, seeds) is present; and (6) back of point bar, lateral bar, or low bench (Castro and Jackson, 2001; Miller and Davis, 2003).

The upper and lower ends of the reach and the locations of cross sections were marked with pieces of steel reinforcing rod (rebar) driven into the streambank above bankfull stage on one bank. Three to five cross sections at each site were placed in riffles or runs, away from channel-constricting structures such as bridges and culverts.

After the preliminary reconnaissance, each study reach was surveyed by methods described in Powell and others (2004). Longitudinal-profile and cross-sectional surveys were conducted. The longitudinal-profile survey consisted of elevation measurements of the rebar markers at the upper and lower reach limits; all bankfull-indicators; and the thalweg and water surface at each bankfull indicator, cross section, and pool-to-riffle transition. The cross-section surveys consisted of surveying bed and bank elevations, bankfull-indicators, rebar that marked cross sections, and the flood-plain width.

The reference elevation for all surveys was the elevation used to define the stage-to-discharge relation at active sites and to develop the stage-to-discharge relation at inactive sites. Channel-bed material throughout the reach was characterized by means of a modified Wolman pebble count (Harrelson and others, 1994).

## Data Analysis

All field data were compiled for graphical analysis. At most sites, a bankfull-elevation profile along the study reach was constructed by plotting a linear regression line through the surveyed bankfull-stage indicators. Bankfull water-surface elevation (stage) and discharge at these sites were derived from these best-fit lines, rather than from surveyed bankfull indicators, to smooth local variations in slope that can result from intermittent disruptions such as debris piles or bedrock outcrops. Bankfull stage and discharge at three sites (Second Creek Tributary at Alton (04232071), Flint Creek at Phelps (04235250), and Tonawanda Creek at Rapids (04218000)) was obtained through a nonparametric regression technique called a loess smooth (locally weighted scatter plot smoothing (aka LOWESS); Ott and Longnecker, 2001) because major changes in slope upstream and (or) downstream from the site, and indistinct bankfull indicators above the site, hindered interpretation of bankfull elevation data (table 1).

The bankfull stage at the gage or staff plate at active and recently discontinued sites was calculated as described above, and the corresponding bankfull discharge was obtained from the most current stage-to-discharge relation. Bankfull discharge at the inactive site was interpolated from the newly developed stage-to-discharge relation that was extended to bankfull stage through Johnson's method (Kennedy, 1984). Estimates of bankfull discharges for all sites were verified

**Table 1.** Characteristics of streamflow-gaging stations surveyed in Region 7 in New York, 2003-04.

[$mi^2$, square miles; $ft^3/s$, cubic feet per second. Site locations are shown in fig. 1B.]

| Site name and USGS station number | Period(s) of record | Drainage area ($mi^2$) | Bankfull discharge[1] ($ft^3/s$) | Recurrence interval of bankfull discharge (years) | Reach stream type[2] |
|---|---|---|---|---|---|
| Second Creek Tributary at Alton (04232071)[3] | 1970-86 | 1.07 | 46 | 3.60 | E5 |
| Canandaigua Outlet Tributary near Alloway (04235255) | 1977-2003 | 2.94 | 79 | 3.00 | E5 |
| East Branch Allen Creek at Pittsford (0423204920) | 1990-2002 | 9.50 | 121 | 1.05 | E4 |
| Northrup Creek at North Greece (0422026250) | 1989-2003 | 10.1 | 438 | 2.60 | C4 |
| Butternut Creek near Jamesville (04245200) | 1958-2003 | 32.2 | 549 | 1.13 | C4 |
| Irondequoit Creek at Railroad Mills near Fishers (04232034) | 1991-present | 39.2 | 435 | 1.70 | C4 |
| Flint Creek at Phelps (04235250)[4] | 1959-95, 2002-present | 102 | 1720 | 3.20 | C4 |
| Irondequoit Creek above Blossom Rd near Rochester (0423205010) | 1980-present | 142 | 1050 | 1.50 | C5c- |
| Oatka Creek at Garbutt (04230500) | 1945-present | 200 | 2310 | 1.80 | F3, B3c |
| Tonawanda Creek at Rapids (04218000)[5] | 1955-65, 1978-present | 349 | 4140 | 1.75 | C4, B4c |

[1] From stage-to-discharge relation.

[2] From Rosgen (1994): B3c: low-gradient, moderately entrenched, riffle-dominated channel with cobbles
B4c: low-gradient, moderately entrenched, riffle-dominated channel with gravel
C4: low-gradient alluvial channel with gravel
C5c-: very low-gradient alluvial channel with sand
E4: sinuous, alluvial channel with gravel
E5: sinuous, alluvial channel with sand
F3: low-gradient, deeply entrenched channel with cobbles
Channel materials from longitudal-profile pebble count.

[3] Loess smooth used to obtain bankfull stage because slope upstream from culvert was much steeper than slope downstream from culvert.

[4] Loess smooth used to obtain bankfull stage because gage was located in flat pool between two steep riffles.

[5] Loess smooth used to obtain bankfull stage because bankfull stage was difficult to identify in pool above gage.

through a hydraulic analysis of the bankfull geomorphologic data collected during the gage calibration survey as described below. Additional details are given in Powell and others (2004).

(1) The computer program NCALC (Jarrett and Petsch, 1985) was used to compute Manning's n, the roughness coefficient for the reach. Data required for this computation were: discharge from the stage-to-discharge relation, channel-bed and bankfull water-surface elevations at each cross section, and the distance along the thalweg between cross sections (Jarrett and Petsch, 1985).

(2) The computer program HEC-RAS (U.S. Army Corps of Engineer's Hydraulic Engineering Center River Analysis System; Brunner, 1997) was used to calculate bankfull discharge from the water-surface elevation, as follows: first, the reference elevation for the survey was entered as the starting elevation, and Manning's n (from the NCALC analysis), channel-bed elevations at each cross section, the distance along the thalweg between cross sections, and several estimated discharges were input for each cross section. The discharge at the water-surface elevation calculated by HEC-RAS that most closely approximated the surveyed bankfull water-surface elevation was chosen as the bankfull discharge at each cross-section; and finally, the average of these discharges from all cross sections in the reach was used as the bankfull discharge for the reach.

(3) The bankfull discharge obtained from the stage-to-discharge relation was compared with the bankfull discharge obtained from the HEC-RAS analysis. If the two discharges differed by 10 percent or less, the discharge obtained from the stage-to-discharge relation was then used as the bankfull discharge, and the recurrence interval of this discharge was calculated. If the two discharges varied by more than 10 percent, the site and reach selection, discharge measurements, elevation of bankfull indicators, and development of the stage-to-discharge relation were reviewed for sources of error. If no errors were found, the discharge that more closely fit the expected 1.5-year bankfull recurrence interval was chosen.

The bankfull discharges from the stage-to-discharge rating agreed with the bankfull discharge from the HEC-RAS analysis at all 10 sites.

# Regional Equations for Bankfull Discharge and Channel Characteristics of Streams

Relations between bankfull discharge, depth, width, and cross-sectional area and drainage area for Region 7 are presented below. The period of record, drainage area, bankfull discharge and associated recurrence intervals, and Rosgen (1994) stream type for each site are summarized in table 1.

## Regionalized Relation Between Bankfull Discharge and Drainage Area

The equation for streams in Region 7 (fig. 2) is:
bankfull discharge ($ft^3/s$) = 37.1 (drainage area, in $mi^2$)$^{0.765}$ and has a coefficient of determination ($R^2$) of 0.94. The 95-percent confidence and prediction intervals for the equation are shown in figure 2. The 95-percent confidence interval defines the range within which results from data collected on a different set of streams in the same region would have a 95-percent probability of occurring, whereas the wider 95-percent prediction interval defines the range within which the bankfull discharge estimated for a single stream of a given drainage area in the region would have a 95-percent probability of occurring. Comparing results from equations developed for other regions, and their 95-percent confidence and prediction intervals, with those obtained for streams of Region 7 can help identify regional differences in stream characteristics.

## Bankfull-Discharge Recurrence Intervals

The recurrence interval for the estimated bankfull discharge of each stream was calculated from regression equations relating measured discharges to known recurrence intervals (R. Lumia, U.S. Geological Survey, 1991; written commun.). Previous investigations reported that the average recurrence interval for bankfull discharge typically ranges from 1 to 2 years (Dunne and Leopold, 1978; Rosgen, 1996; Harman and Jennings, 1999). The bankfull-discharge recurrence interval for streams surveyed in Region 7 ranged from 1.05 to 3.60 years, and averaged 2.13 years (table 1). Previous investigations in Regions 4 and 4a (fig. 1) found an average bankfull-discharge recurrence interval of 1.54 years and a range of 1.2 to 2.7 years (Miller and Davis, 2003), in Region 5 (fig. 1) found an average of 1.51 years and a range of 1.11 to 3.40 years (Westergard and others, 2005), and in Region 6 (fig. 1) found an average of 1.54 years and a range of 1.01 to 2.35 years (Mulvihill and others, 2005). The higher-than-expected recurrence interval of bankfull discharge in Region 7 suggests that local factors such as sparse forest coverage and a high basin shape index might affect the relation between discharge and drainage area (Lumia, 1991).

## Stream-Channel Dimensions in Relation to Drainage Area

Regression equations for bankfull channel width, depth, and cross-sectional area for streams of Region 7 are as follows:

bankfull channel width (ft) = 10.8 (drainage area, in $mi^2$)$^{0.458}$
bankfull channel depth (ft) = 1.47 (drainage area)$^{0.199}$
bankfull channel cross-sectional area ($ft^2$) = 15.9 (drainage area)$^{0.656}$

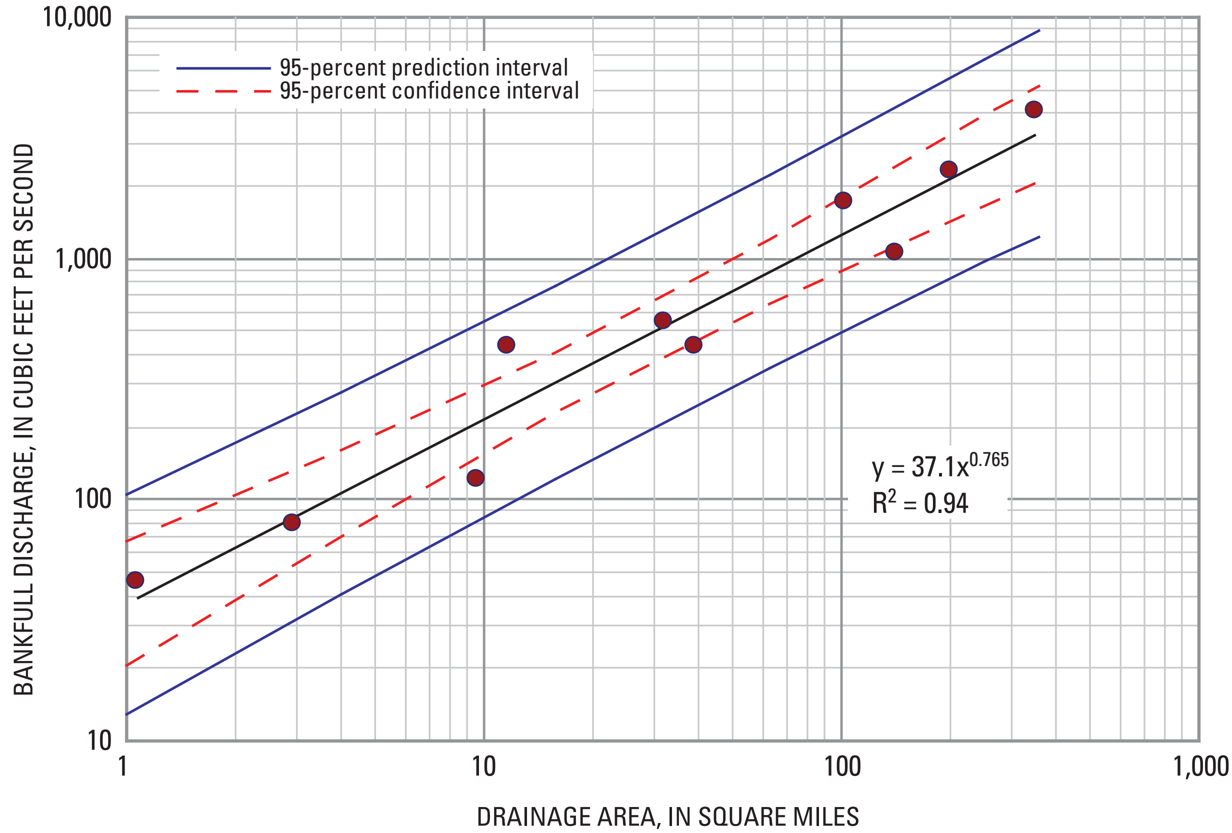



**Figure 2.** Bankfull discharge (y) as a function of drainage area (x) for streams surveyed in Region 7 in New York, with 95-percent prediction and confidence intervals.

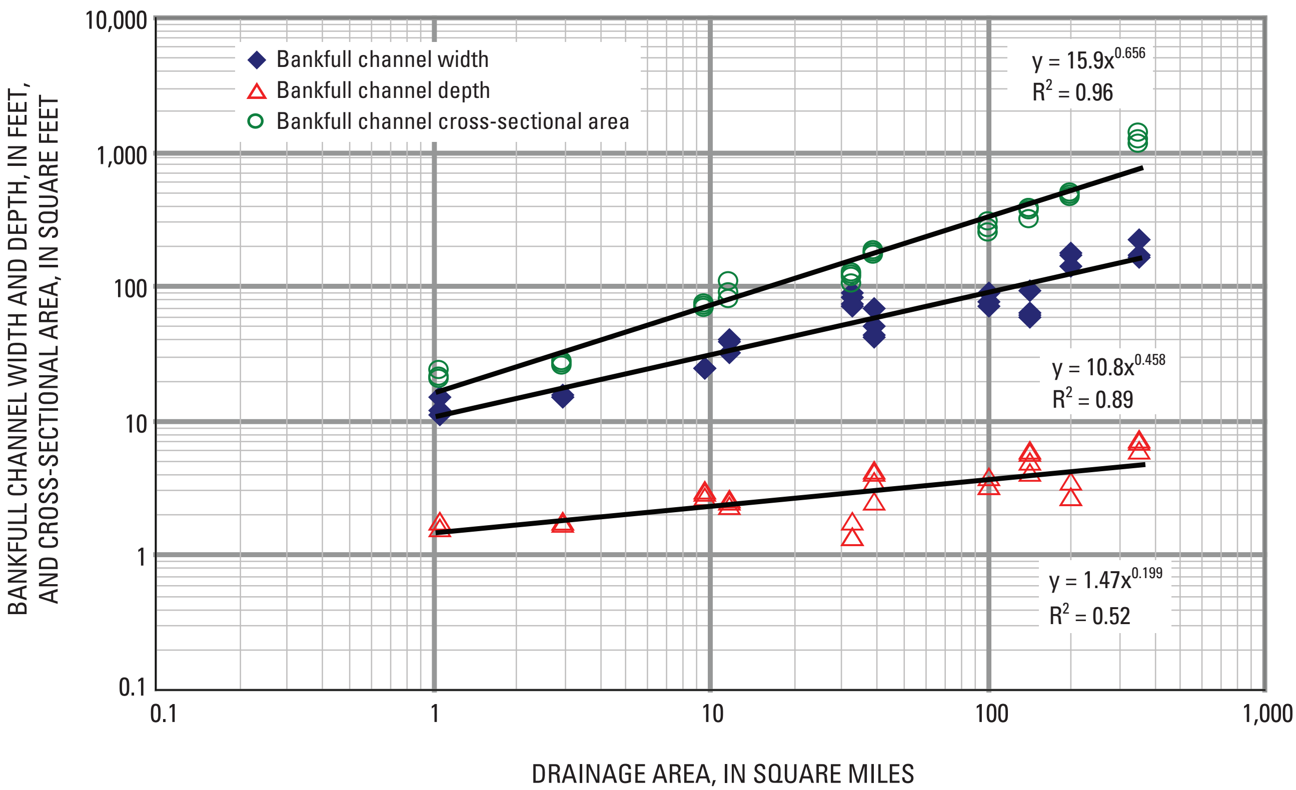



**Figure 3.** Bankfull channel width, depth, and cross-sectional area (y) as a function of drainage area (x) for all streams surveyed in Region 7 in New York, with best-fit lines, regression equations, and coefficient of determination ($R^2$) values.

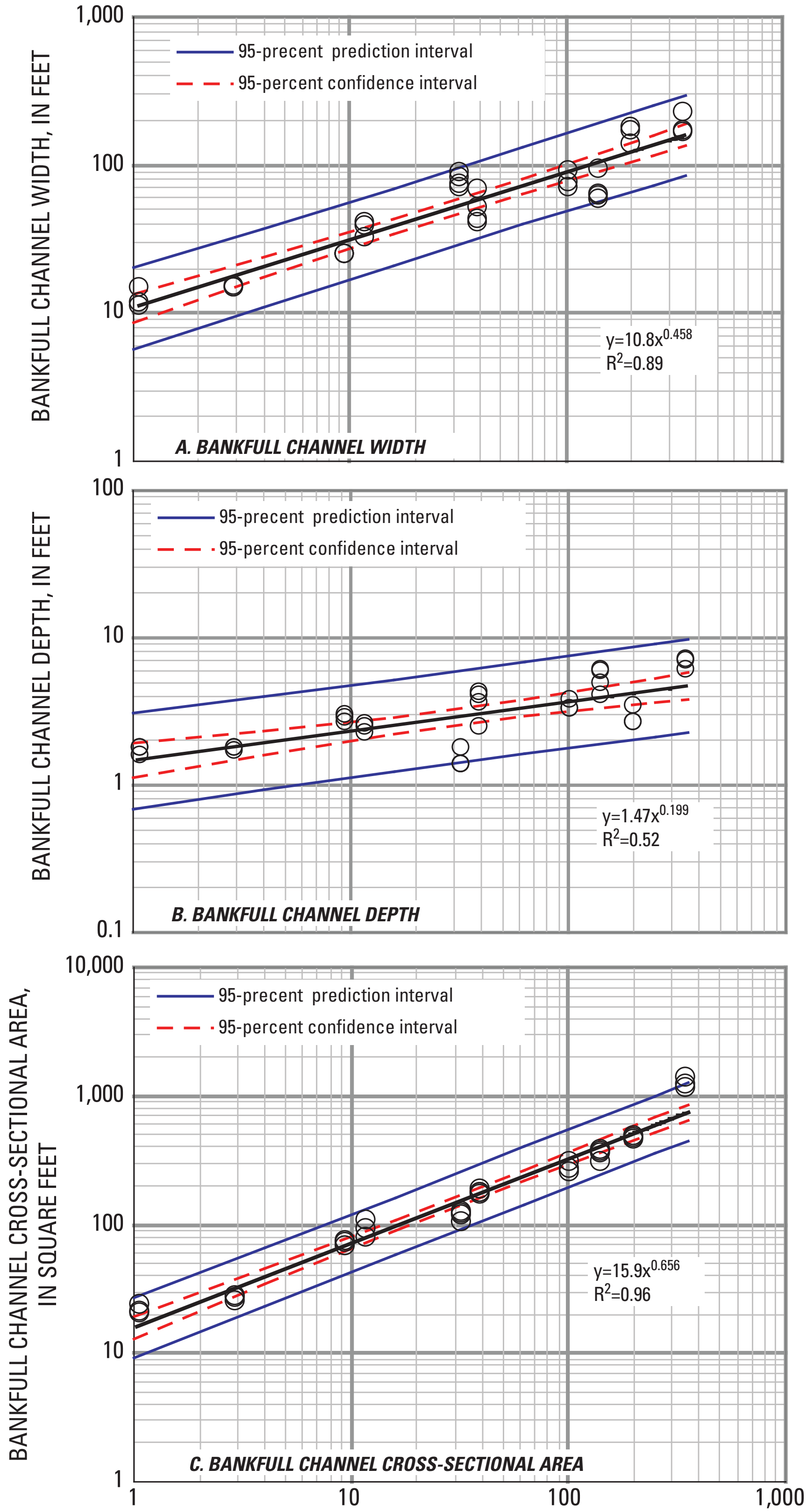



**Figure 4.** Mean channel dimensions (y) as a function of drainage area (x) for streams in Region 7 in New York, with 95-percent prediction and confidence intervals: *A*. Bankfull channel width. *B*. Bankfull channel depth. *C*. Bankfull channel cross-sectional area.

Results are plotted in figure 3; rounded coefficients of determination ($R^2$) for the equations were 0.89, 0.52, and 0.96, respectively. The high coefficients of determination ($R^2$) for equations relating drainage area to bankfull channel width and cross-sectional area indicate that much of the range in these two variables is explained by drainage area alone. The lower coefficient of determination for the equation that relates drainage area to bankfull channel depth, suggests that other factors, such as basin shape, vegetation, and channel materials (Leopold, 1994), could also affect this relation.

The raw data for Region 7 equations and the corresponding 95-percent confidence and prediction intervals are provided in plots of mean bankfull channel width, depth, and cross-sectional area as a function of drainage area in figures 4A through 4C, respectively.

## Stream Classification

The Rosgen classification system (Rosgen, 1996) categorizes streams on the basis of channel morphology to provide consistent, quantitative descriptions of stream condition (Harman and Jennings, 1999). The current study used the following criteria and measurements to classify streams; the values obtained in this study are given in table 2.

*Entrenchment ratio:* a field measurement of channel incision, defined as the flood-plain width divided by the bankfull width (Harman and Jennings, 1999). The flood-plain width is measured at the elevation of twice the maximum depth at bankfull.

*Width-to-depth ratio:* the bankfull width divided by the mean bankfull depth (Harman and Jennings, 1999).

*Water-surface slope:* the difference between the water-surface elevation at the upstream end of a riffle to the upstream end of another riffle at least 20 bankfull widths downstream, divided by the distance between the riffles along the thalweg (Harman and Jennings, 1999).

*Median size (D50) of bed material:* the median particle size, or the diameter that exceeds the diameter of 50 percent of all streambed particles (Harman and

Jennings, 1999). D50 values were obtained through a modified Wolman pebble count (modified to account for bank and in-channel material, sand and smaller particle sizes, and bedrock (Rosgen 1996)).

*Sinuosity:* stream length divided by valley length (Harman and Jennings, 1999).

Each reach was classified by Rosgen stream type using the average of stream-channel measures taken at each cross section (table 1). Each cross section was also classified individually by Rosgen stream type (table 2). Stream types “A” through “G” represent seven major stream categories that differ in entrenchment, gradient, width-to-depth ratio, and sinuosity (Rosgen, 1996). Within each major category, the numbers 1 through 6 are assigned to delineate dominant channel material ranging from bedrock to silt and clay along a continuum of gradient ranges (Rosgen, 1996). The designation of the major stream category for two of the sites resulted in the placement of some cross sections into different stream types within a single reach; both of these resulted from differences in the entrenchment ratios.

Of the 10 streams surveyed, eight were classified exclusively as type C or E, one had two F and one B cross section, and one had two C and one B cross section (table 1). One of the C streams had a slope less than 0.001 and, therefore, was classified as a Cc- reach. Both of the B cross sections had slopes less than 0.02 and, therefore, were classified as Bc (Rosgen, 1996). The predominance of C- and E-type reaches within Region 7 indicated a similarity among streams, in that C- and E-type reaches have the same entrenchment ratios and differ mostly in width-to-depth ratios. The presence of B- and F-type cross sections in these streams shows the region’s variability in stream geomorphology.

## Comparison of Region 7 Equation to Equations for Other Regions

The Region 7 equation for the relation between bankfull discharge and drainage area was compared with the equations developed for streams in four other hydrologic regions in New York. Small to moderate differences among the five curves indicate that regional curves relating bankfull discharge and channel characteristics to drainage-area provide more reliable data for local stream restoration efforts (fig. 5). For example, the Region 4a curve (Miller and Davis, 2003) has a much steeper slope than the Region 7 curve, possibly reflecting the mountainous topography of Region 4a, which can yield greater runoff than lowland or valley regions (Randall, 1996). The slope of the Region 7 curve is similar to that of the Region 4 curve (Miller and Davis, 2003), but the Region 4 curve lies above the 95-percent confidence interval of Region 7, as do curves for Regions 5 and 6, except at small drainage areas. Bankfull discharge is generally lower in Region 7 than in the other regions for comparable drainage areas, possibly a result of a lower mean annual precipitation and runoff in Region 7 than in the other regions (Randall, 1996).

# Limitations of this Study

An assumption made in this investigation – that the bankfull discharge of a stream was within the 1- to 2-year recurrence-interval range – may be an oversimplification (Thorne and others, 1997), though similar recurrence intervals have been found in other studies (Harman and Jennings, 1999; Rosgen, 1994). Channel dimensions associated with a 1- to 2-year recurrence interval were used to aid in the identification of bankfull indicators during initial site inspections, but if the bankfull discharge recurrence interval at a site were longer or shorter than that frequency, the bankfull channel could be incorrectly identified (White, 2001). The average bankfull discharge recurrence interval for streams surveyed in Region 7 was 2.13 years, which is slightly longer than the average 1.5 year frequency predicted by Rosgen (1996), but still within the 1- to 2.5-year range predicted by Leopold (1994).

The small number of active USGS streamflow-gaging stations in Region 7 that met selection criteria was also a limiting factor in this investigation. Three sites that had been inactive for 2-17 years and two sites that represented more than one stream type within the study reach were included in the study, necessitating several assumptions. Analysis of data from the inactive streamflow-gaging stations assumed that: (1) the recurrence interval of bankfull discharge had not changed since the site was last active, (2) the flow pattern at the site had not been significantly altered by floods, diversions, ground-water recharge, or changes in land use since the site was discontinued, and (3) three low- to medium-flow discharge measurements were sufficient to define a stage-to-discharge relation that could reliably be extended to bankfull stage. Data analysis for the sites representing several stream types assumed that averaging measurements from cross sections of differing types was an accurate measure of overall reach characteristics.

At three other sites, bankfull indicators upstream and (or) downstream of the gage either varied widely or indicated a change in slope. In these cases, it was assumed that the bankfull indicators near the gage, which were readily identifiable and matched the anticipated return interval, could be used to extrapolate bankfull stage and channel dimensions accurately through a loess smooth (table 1).

Regional channel-geometry equations can be more reliable than those representing an entire state or larger area in the design of stream-restoration projects, enhancement of fish habitat, and adjustment of in-stream and riparian structures (Castro and Jackson, 2001). Users of regional relations must recognize their limitations, however, and accept that these regression equations are designed to provide only estimates of bankfull-channel dimensions and discharges, and are not intended to substitute for the field measurement and verification of bankfull channel dimensions and streamflow (White, 2001).

**Table 2.** Stream classification and bankfull hydraulic-geometry data for cross sections at the 10 USGS streamflow-gaging stations surveyed in Region 7 in New York, 2003-04.

[ft, feet; ft², square feet; mi², square miles; mm, millimeters. Site locations are shown in fig. 1B.]

| Site name and station-identification number | Drainage area (mi²) | Cross-section downstream stationing (ft) | Bankfull width (ft) | Bankfull depth (ft) | Bankfull cross-sectional area (ft²) | Width of flood-plain (ft) | Entrenchment ratio[1] | Width-to-depth ratio | Water surface slope | D50[2] (mm) | Sinuosity[3] | Cross-section stream type[4] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Second Creek Tributary at Alton (04232071) | 1.07 | 324 | 11.9 | 1.8 | 20.9 | 190 | 16.0 | 6.6 | 0.007 | 0.5 | 1.22 | E5 |
| | | 385 | 14.9 | 1.6 | 24.2 | 248 | 16.6 | 9.3 | | | | E5 |
| | | 432 | 11.1 | 1.8 | 20.3 | 185 | 16.7 | 6.2 | | | | E5 |
| Canandaigua Outlet Tributary near Alloway (04235255) | 2.94 | 56 | 14.9 | 1.8 | 26.7 | 302 | 20.3 | 8.3 | 0.004 | 0.1 | 1.10 | E5 |
| | | 68 | 15.4 | 1.8 | 27.5 | 303 | 19.7 | 8.6 | | | | E5 |
| | | 79 | 15.0 | 1.7 | 25.3 | 302 | 20.1 | 8.8 | | | | E5 |
| East Branch Allen Creek at Pittsford (0423204920) | 9.50 | 146 | 24.9 | 2.9 | 72.5 | 170 | 6.8 | 8.6 | 0.003 | 4.8 | 1.23 | E4 |
| | | 172 | 25.0 | 2.7 | 68.3 | 164 | 6.6 | 9.3 | | | | E4 |
| | | 203 | 24.8 | 3.0 | 74.3 | 170 | 6.9 | 8.3 | | | | E4 |
| Northrup Creek at North Greece (0422026250) | 10.1 | 714 | 39.2 | 2.3 | 91.3 | 228 | 5.8 | 17.0 | 0.006 | 54.5 | 1.21 | C4 |
| | | 766 | 32.8 | 2.5 | 80.4 | 244 | 7.4 | 13.1 | | | | C4 |
| | | 830 | 40.6 | 2.6 | 107 | 267 | 6.6 | 15.6 | | | | C4 |
| Butternut Creek near Jamesville (04245200) | 32.2 | 162 | 70.9 | 1.8 | 127 | 480 | 6.8 | 39.4 | 0.005 | 40.5 | 1.15 | C4 |
| | | 1036 | 88.8 | 1.4 | 122 | 542 | 6.1 | 63.4 | | | | C4 |
| | | 1097 | 82.5 | 1.4 | 118 | 664 | 8.0 | 58.9 | | | | C4 |
| | | 1176 | 74.2 | 1.4 | 105 | 495 | 6.7 | 53.0 | | | | C4 |
| Irondequoit Creek at Railroad Mills near Fishers (04232034) | 39.2 | 74 | 41.3 | 4.3 | 177 | 309 | 7.5 | 9.6 | 0.003 | 10.9 | 2.85 | C4 |
| | | 220 | 43.6 | 4.1 | 179 | 270 | 6.2 | 10.6 | | | | C4 |
| | | 351 | 69.4 | 2.5 | 173 | 314 | 4.5 | 27.8 | | | | C4 |
| | | 501 | 51.3 | 3.6 | 187 | 364 | 7.1 | 14.3 | | | | C4 |

**Table 2.** Stream classification and bankfull hydraulic-geometry data for cross sections at the 10 USGS streamflow-gaging stations surveyed in Region 7 in New York, 2003-04.—(Continued)

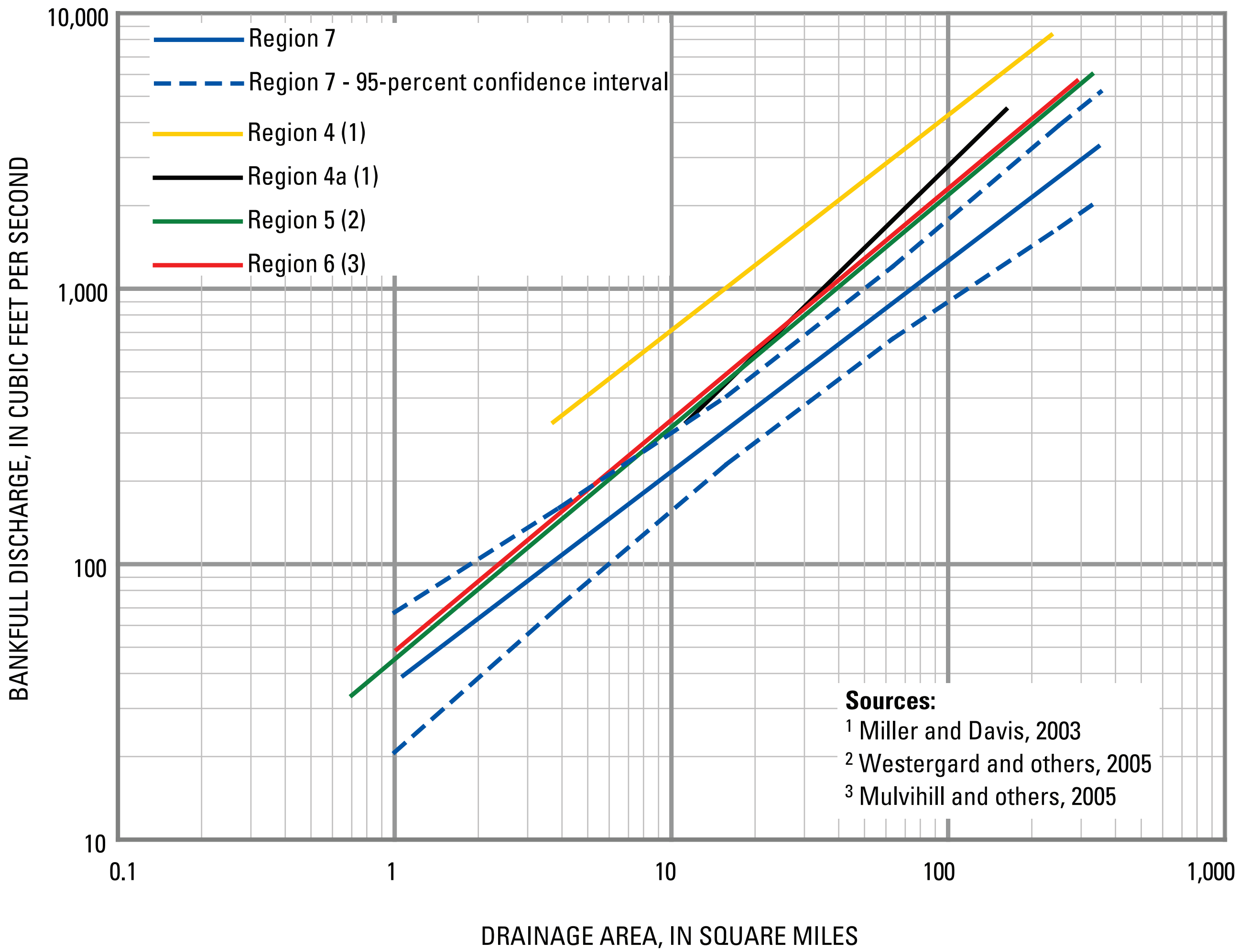
| Site name and station-identification number | Drainage area ($mi^2$) | Cross-section downstream stationing (ft) | Bankfull width (ft) | Bankfull depth (ft) | Bankfull cross-sectional area ($ft^2$) | Width of flood-plain (ft) | Entrenchment ratio[1] | Width-to-depth ratio | Water surface slope | D50[2] (mm) | Sinuosity[3] | Cross-section stream type[4] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flint Creek at Phelps (04235250) | 102 | 591 | 91.2 | 3.3 | 304 | 352 | 3.9 | 27.6 | 0.010 | 27.0 | 1.18 | C4 |
| | | 658 | 70.7 | 3.8 | 271 | 331 | 4.7 | 18.6 | | | | C4 |
| | | 725 | 75.9 | 3.3 | 253 | 331 | 4.4 | 23.0 | | | | C4 |
| Irondequoit Creek above Blossom Road near Rochester (0423205010) | 142 | 159 | 62.2 | 5.0 | 312 | 715 | 11.5 | 12.4 | 0.0005 | 0.1 | 5.79 | C5c- |
| | | 1818 | 59.6 | 6.1 | 361 | 385 | 6.5 | 9.8 | | | | C5c- |
| | | 1944 | 94.3 | 4.1 | 382 | 415 | 4.4 | 23.0 | | | | C5c- |
| | | 2013 | 63.8 | 5.9 | 376 | 399 | 6.3 | 10.8 | | | | C5c- |
| Oatka Creek at Garbutt (04230500) | 200 | 291 | 172 | 2.7 | 465 | 204 | 1.2 | 63.6 | 0.003 | 70.6 | 1.17 | F3 |
| | | 466 | 178 | 2.7 | 478 | 229 | 1.3 | 66.0 | | | | F3 |
| | | 1032 | 141 | 3.5 | 489 | 250 | 1.8 | 40.1 | | | | B3c |
| Tonawanda Creek at Rapids (04218000) | 349 | 1218 | 166 | 7.0 | 1160 | 285 | 1.7 | 23.7 | 0.001 | 18.4 | 3.27 | B4c |
| | | 1347 | 228 | 6.1 | 1380 | 1250 | 5.5 | 37.3 | | | | C4 |
| | | 1464 | 169 | 7.2 | 1210 | 1260 | 7.5 | 23.5 | | | | C4 |

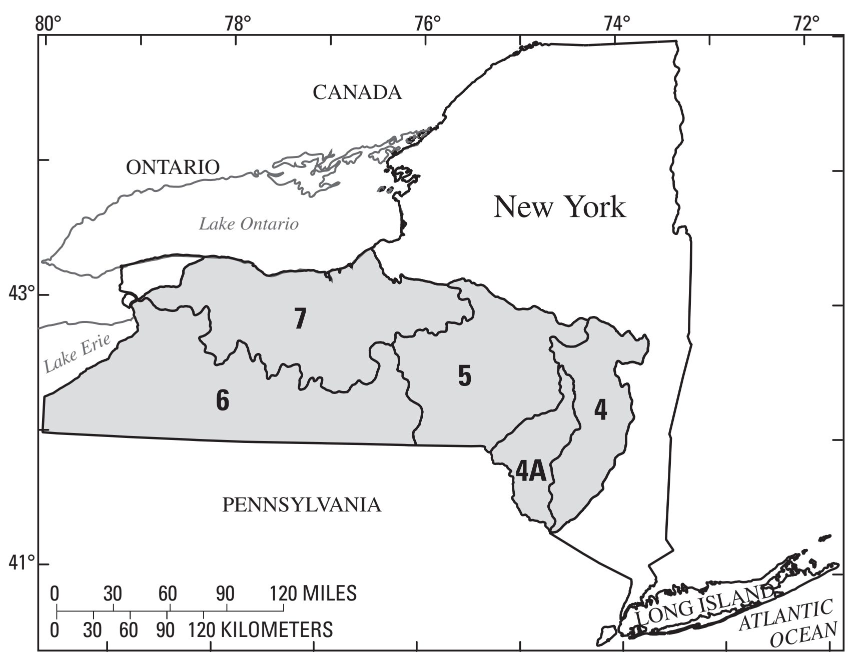
[1] Entrenchment ratio: flood-plain width divided by bankfull width (Harman and Jennings, 1999).

[2] D50: median particle size, the diameter that exceeds that of 50 percent of all streambed particles in the reach (obtained through a modified Wolman pebble count).

[3] Sinuosity: ratio of stream length to valley length (Harman and Jennings, 1999).

[4] From Rosgen (1994):
- B3c: low-gradient, moderately entrenched, riffle-dominated channel with cobbles
- B4c: low-gradient, moderately entrenched, riffle-dominated channel with gravel
- C4: low-gradient, alluvial channel with gravel
- C5c-: very low-gradient alluvial channel with sand
- E4: sinuous, alluvial channel with gravel
- E5: sinuous, alluvial channel with sand
- F3: low-gradient, deeply entrenched channel with cobbles




Base from U.S. Geological Survey digital data

**Figure 5.** Bankfull discharge as a function of drainage area for Region 7 in New York and published curves for four other regions in New York State.

## Summary and Conclusions

Equations relating bankfull discharge and channel dimensions (width, depth, and cross-sectional area) to the size of the drainage area at gaged stream sites are needed to predict bankfull discharge and channel dimensions at ungaged stream sites and to provide information used in the design of stream-restoration projects. The U.S. Geological Survey (USGS), in cooperation with the New York State Department of Environmental Conservation (NYSDEC), the New York State Department of Transportation (NYSDOT), the New York City Department of Environmental Protection (NYCDEP), and the New York State Department of State (NYSDOS) undertook a study to develop these equations for streams in western New York (Region 7). Stream-survey data and discharge records from seven active and three inactive USGS streamflow-gaging stations were used in regression analyses to relate drainage area to bankfull discharge and to bankfull channel width, depth, and cross-sectional area. The resulting equations are:

bankfull discharge ($ft^3/s$) = 37.1 (drainage area, in $mi^2$)$^{0.765}$
bankfull channel width (ft) = 10.8 (drainage area)$^{0.458}$
bankfull channel depth (ft) = 1.47 (drainage area)$^{0.199}$
bankfull channel cross-sectional area ($ft^2$) = 15.9 (drainage area)$^{0.656}$

The high coefficient of determinations ($R^2$) for bankfull discharge, width, and cross-sectional area (0.94, 0.89, and 0.96, respectively) indicate that much of the variation in these factors is explained by the size of the drainage area. The smaller coefficient of determination between drainage area and bankfull channel depth (0.52) suggests that drainage area alone cannot be used to predict this variable accurately.

Recurrence intervals of bankfull discharges were calculated for each stream through regression equations that relate measured discharges to known recurrence intervals. The recurrence intervals for bankfull discharge of the 10 surveyed streams in Region 7 ranged from 1.05 to 3.60 years, with a mean recurrence interval of 2.13 years. Streams were classified by Rosgen stream type on the basis of specific channel characteristics at each surveyed cross section. Most streams were C- and E-type, with occasional B- and F-type cross-sections.

The Region 7 equation for the relation between bankfull discharge and drainage area was compared with equations developed for four other hydrologic regions in New York State. Differences in results from the five equations indicate a need to develop equations by region to improve their accuracy.

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